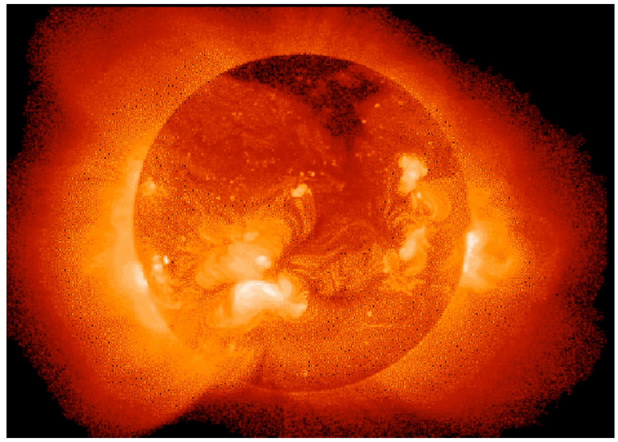
Creation of Plasma – Teacher Demonstrations

Time:
10 minutes – Part 1 - Modeling creation of plasma
15 minutes – Part 2 - Creating plasma


X-ray image of the Sun from Yohkoh

Objective:
To build an understanding of how energy translates to temperature. How collisions between particles at high velocity strip or gain electrons from other atoms and molecules making them “ions”.

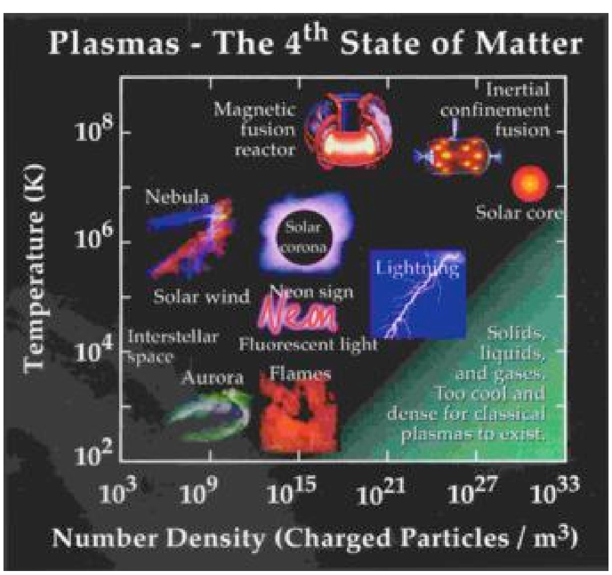
Content Standards:
Abilities necessary to do scientific inquiry
- Identify questions and concepts that guide scientific investigations
- Design and conduct scientific investigations
- Formulate and revise scientific explanations and models using logic and evidence
- Recognize and analyze alternative explanations and models
- Use Technology and Mathematics to improve investigations and communications
- Formulate and revise scientific explanations and models using logic and evidence
- Communicate and defend a scientific argument

Equipment, Materials, and Tools

Part 1
- Hard, over-baked, cookies.
- A brush and pan to pick up the crumbs.

Part 2
- Tesla Coil (spark generator)
- Pieces of metal and various non-conductors

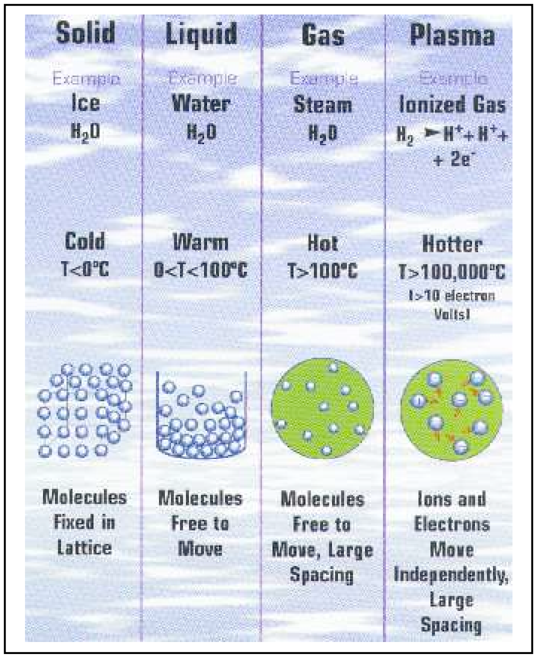
Background Information:
The plasma in space is significantly different from that in stars because of the extremely low density. The particles, though traveling at extremely high speeds (high temperature) seldom, if ever, collide with anything, and therefore do not have a chance to de-ionize. The fact that they are ions, that is, charged particles, and that they have great velocity and a relatively consistent direction, in effect makes them a powerful electric current through space.



Plasmas are conductive assemblies of charged particles, neutrals and fields that exhibit collective effects. Further, plasmas carry electrical currents and generate magnetic fields. Plasma is by far the most common form of matter. Plasma in the stars and in the tenuous space between them makes up over 99% of the visible universe and perhaps most of that which is not visible.

On earth we live upon an island of "ordinary" matter. The different states of matter generally found on earth are solid, liquid, and gas. We have learned to work, play, and rest using these familiar states of matter. Sir William Crookes, an English physicist, identified a fourth state of matter, now called plasma, in 1879.

Plasma temperatures and densities range from relatively cool and tenuous (like aurora) to very hot and dense (like the central core of a star). Ordinary solids, liquids, and gases are both electrically neutral and too cool or dense to be in a plasma state.



The word "PLASMA" was first applied to ionized gas by Dr. Irving Langmuir, an American chemist and physicist, in 1929.

Plasma consists of a collection of free-moving electrons and ions - atoms that have lost electrons. Energy is needed to strip electrons from atoms to make plasma. The energy can be of various origins: thermal, electrical, or light (ultraviolet light or intense visible light from a laser). With insufficient sustaining power, plasmas recombine into neutral gas.

Plasma can be accelerated and steered by electric and magnetic fields that allow it to be controlled and applied. Plasma research is yielding a greater understanding of the universe.
The full range of possible plasma density, energy (temperature) and spatial scales go far beyond this illustration. For example, some space plasmas have been measured to be less than $10^{-1}/m^3$ (13 orders of magnitude less than the scale shown in the figure!). On one extreme, quark-gluon plasmas (although mediated via the strong force field versus the electromagnetic field) are extremely dense nuclear states of matter. For temperature (or energy), some plasma crystal states produced in the laboratory have temperatures close to absolute zero. On the other extreme, space plasmas have been measured with thermal temperatures above 10^9 degrees Kelvin and cosmic rays (a type of plasma with very large gyroradii) are observed at energies well above those produced in any man-made accelerator laboratory.

Instructions: part 1 – Teacher Demonstration

Modeling the creation of plasma (ions)

1. Drop a “hard” cookie – modeling of gas collisions
   - Atoms and molecules are always running into each other in the gas phase, but seldom is there enough energy in those collisions under “gas” like temperatures for electrons to be exchanged.
2. Throw cookie to hit table or floor – modeling of plasma collisions
   - At the very high temperatures in a star, which translate in the case of atoms and molecules to very high speeds, the collisions are sufficiently energetic to in this case break up the cookie, in the case of a plasma strip or gain electrons.
3. Conduct a class discussion to further build understanding of gas collisions and the creation of ions.

Creating a Plasma – Teacher Demonstration

Part 2: Creating a Plasma

Background Information:

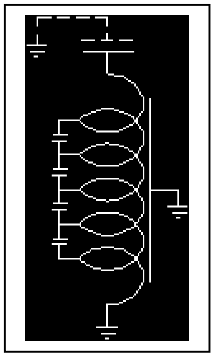
The Tesla Coil uses a very high voltage to generate sparks in ordinary atmosphere. The color of the sparks generated is usually purple. One can smell the ozone ions being created; the very high voltage is ionizing the atmosphere in the vicinity. These are actually mini-lightning charges. Besides being able to smell ions the students will hear the constant, very small discharges occurring while the Tesla Coil is on. This device is safe to humans, but does deliver a sharp unpleasant jolt. Ask the students to suggest ways to test the device. After one grabs it there is no further great effect, but the courage to grab it is difficult to muster.

The ions show up better if the classroom lights are off. Some student invariably thinks of putting a piece of paper in position so that the sparks can pass through it. If done so for a few seconds, the paper will light on fire, demonstrating the "heat" of the ions in the sparks though no great amount of heat is felt near the tip. If time and interest allow, the students can investigate where on the shape of the tip of the device do the sparks prefer to emanate. Also be sure to demonstrate how the sparks go further and are longer toward electrical conductors and especially objects that are electrically grounded such as the faucets. It does no harm to the running water, as the spark actually prefers the metal.

(The following is from http://www.apc.net/bturner/coils.htm)

What is a Tesla Coil? It is an air-cored, resonant transformer that is capable of producing a very high voltage and visual discharges.

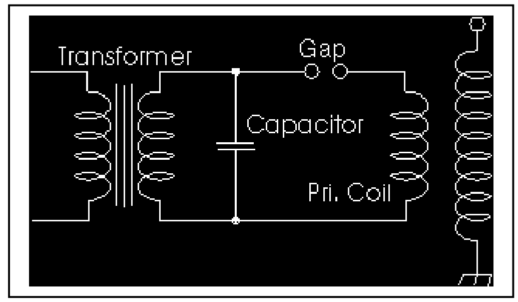
How does it work?
As mentioned, Tesla coils are resonant transformers. This implies that there is a specific frequency at which they operate - *the resonant frequency*. There is no "special" universal Tesla coil frequency - rather, you either target a frequency in the design, or tune a coil into whatever frequency it happens to be happy with.

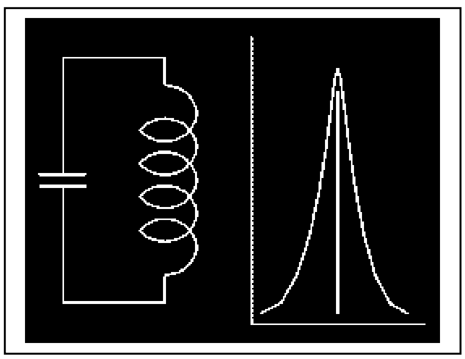


What determines this resonant frequency is the secondary coil - a complex LCR network. The inductive (L) component is the physical coil itself, and is based upon the number of turns, the diameter and length of the coil. The capacitive (C) component is comprised of several *isotropic* values: the surface of the secondary wire and the terminal electrode. (Isotropic capacitance in essence is 'virtual' capacitance - there is a capacitive effect even though it appears that there aren't any physical plates to create the capacitor.) The resistive (R) component consists of the wire itself, and identifies the physical resistance of the secondary coil *at the resonant frequency*.

To get the secondary to resonate, pulses of energy have to be fed at just the right rate and frequency. A good analogy is that of a bell. To get the bell to ring, you need to tap it with a hammer. If you tap too hard, you can crack the bell. If you tap and hold the hammer on the bell too long, you don't get a clean, pure tone out of the bell.

Energy pulses come from the primary circuit. This circuit is made up of (1) the high-voltage transformer, (2) the primary capacitor, (3) the spark gap and (4) the primary coil. Together, these parts form a crude type of oscillator. What happens is thus: the transformer charges the capacitor up until there is a high enough voltage across the spark gap to jump the air gap. When this spark occurs, the energy stored in the capacitor is 'dumped' into the primary inductor. The primary inductor then builds a magnetic field as the capacitor's energy flows through it. The magnetic field will eventually collapse, and will in turn dump what energy is left back into the capacitor. This see-saw activity continues until there isn't enough voltage left to jump the spark gap.





The oscillation frequency is determined by the value of the primary capacitor and the primary inductor. Together, they form what is called a *parallel-resonant* circuit. In typical Telsa coil designs, the frequency is adjusted by altering the primary coil's inductance.

If the energy bursts are of the same frequency as the secondary, the energy transferred by the primary's magnetic field will start to build up in the secondary coil. Much like a laser, this energy grows and amplifies itself until there is an incredible voltage built up at the top of the coil, which dissipates into the air in the form of electrical sparks.